Estimation of starting and stopping loads of AGARD- B standard model and flow angularity of 1.2 m Trisonic Wind Tunnel

A Project Report by

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Submitted in fulfillment for the completion of

B.TECH PROJECT

Under the guidance of

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15 Abstract (*about 200 words*)

Wind Tunnels are essential in Experimental Aerodynamics used for testing scaled models in controlled conditions. Wind Tunnel calibrations are of prime importance in the operational cycle for any wind tunnel. In the current environment of increased data accuracy requirements, it is imperative that accurate and complete wind tunnel calibrations and verifications are established. It is necessary to compare the aerodynamic data with the standard data as part of the calibration process of the wind tunnel. Such a standard is established through the use of standard calibration models such as AGARD, ONERA, HB-2, etc. The test of the standard model serves to confirm the overall accuracy and repeatability of measurements in wind-tunnel facility by comparing the test data with the standard data. We are intended to estimate the start, stop and steady load of the Trisonic wind tunnel facility in VSSC Trivandrum while testing AGARD B Standard Model A program is made to process the pressure data of flow angularity probe and calculate the flow angularity of the Trisonic wind tunnel facility from the acquired data.

16 Subject terms (*Key words*): Experimental Aerodynamics, Scaled Model, Calibration, Trisonic Wind Tunnel, Standard Model, AGARD B, Flow Angularity Measurement

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BONAFIDE CERTIFICATE

*This is to certify that this is a bonafide report of the project titled "**Estimation of starting and stopping loads of AGARD – B standard model and flow angularity of 1.2 m Trisonic Wind Tunnel**" by Anagha Varier P K, Aparna S, Arathi Krishnan K and Gorbin Mathew for fulfillment of Final Year B.Tech Project.*

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Project Team

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Nomenclature

Gamma	: Specific heat ratio
α	: Angle of Attack
TWTP	: Trisonic Wind Tunnel Project
q	: Dynamic Pressure
P	: Static pressure
Po	: Stagnation pressure
T	: Static temperature
To	: Stagnation temperature
ρ	: Density of the fluid
R	: Specific gas constant (287 J/kgK)
v	: Velocity of fluid in medium
P_t	: Total pressure of tunnel flow at time the shock system passes over the mode
S	: Lifting surface planform area
C_{NS}	: Starting load normal force coefficient
F_{NM}	: Maximum Normal force
αF	: Flow angularity in pitch plane
αP	: Probe error in pitch plane
α_N	: Normal probe roll orientation
α_I	: Inverted probe roll orientation

CHAPTER 1

INTRODUCTION

Indian Space Research Organization (ISRO) is India’s primary agency for performing tasks related to space based application, space exploration and development of related techniques. Wind tunnel testing is essential for development of launch vehicles.

Wind tunnel testing, not only provides the aerodynamic data but also an insight to the complex flow interactions. The experimental study done in a wind tunnel involves measuring pressures, temperatures, forces, moments and other aerodynamic parameters on a geometrically similar scale model. Continuous interaction between analytical methods on one hand and experimental simulation on other hand is essential for arriving at reasonably accurate solutions to many of the practical aerospace problems. Standard Models are normally used to calibrate a wind tunnel.

Objectives of Project:

- Study about the wind tunnel facility
- Estimation of start and stop loads on AGARD-B model
- Estimation of flow angularity

CHAPTER 2

WIND TUNNEL

2.1 Introduction

Wind tunnels are devices which provide an airstream flowing under controlled conditions and can measure various aerodynamic parameters.

2.2 Wind Tunnel Classification

Depending upon the *flow Mach no* (the ratio of velocity of the object to the velocity of the air in the medium at same condition) in the test section, the wind tunnels are classified as:

TYPE	MACH NUMBER RANGE
Subsonic wind tunnel	<0.8
Transonic wind tunnel	0.8-1.2
Supersonic wind tunnel	1.2-5
Hypersonic wind tunnel	5-20

Table 1: Wind Tunnel Classification

Depending upon the way of achieving the pressure ratio employed in the tunnels, wind tunnels can be classified as

- Blow down tunnel
- In draft tunnel
- Pressure-Vacuum tunnel

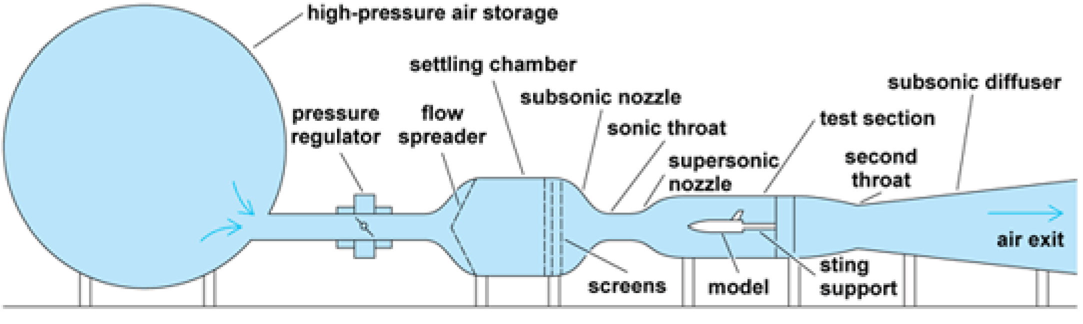


Figure 1: Blow down tunnel

2.2.1 Blow down tunnel

In this type of tunnel, high pressure air is stored in the tanks using a compressor. During running of tunnel, it is vented to atmospheric pressure. There is no vacuum tank in the downstream.

2.2.2 In draft tunnel

These wind tunnels store energy as a pressure difference between the atmosphere and a low pressure tank(vacuum).During operation, the air flows from the atmosphere, through the tunnel, and into the vacuum tank, causing the tank pressure to rise. The run ends when the ratio of atmospheric pressure to tank pressure decreases below that required to drive the tunnel.

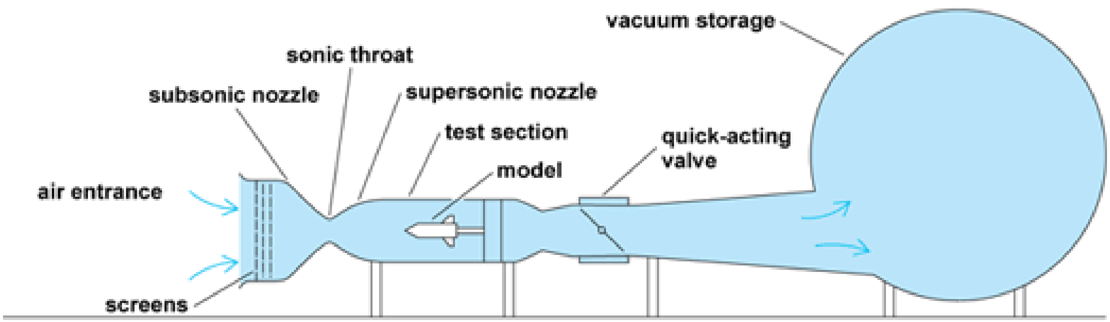


Figure 2: In draft Tunnel

2.2.3 Pressure-Vacuum tunnel

In this type of tunnel, high pressure air is stored as in blowdown tunnels and vacuum is stored as in indraft tunnels. By exhausting the tunnel to a low pressure, the overall tunnel pressure ratio required for operation at a given Mach number can be achieved at a greatly reduced operating pressure. This type is mainly used for hypersonic wind tunnels to cater the higher pressure ratio.

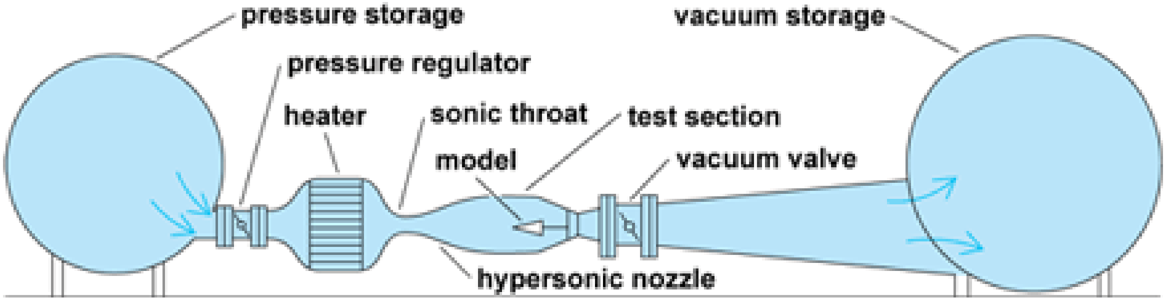


Figure 3: Pressure-Vacuum tunnel

2.3. Trisonic windtunnels: -

The Trisonic wind tunnel is a blowdown facility consisting of a high pressure compressor System, storage vessels, pressure regulating valve, settling chamber, flexible nozzle, test sections, diffuser system, ejector system and muffler. Subsonic, Transonic, Supersonic are the 3 regimes in which the Trisonic wind tunnel works.

2.4 Elements of a Tri-sonic Wind Tunnel

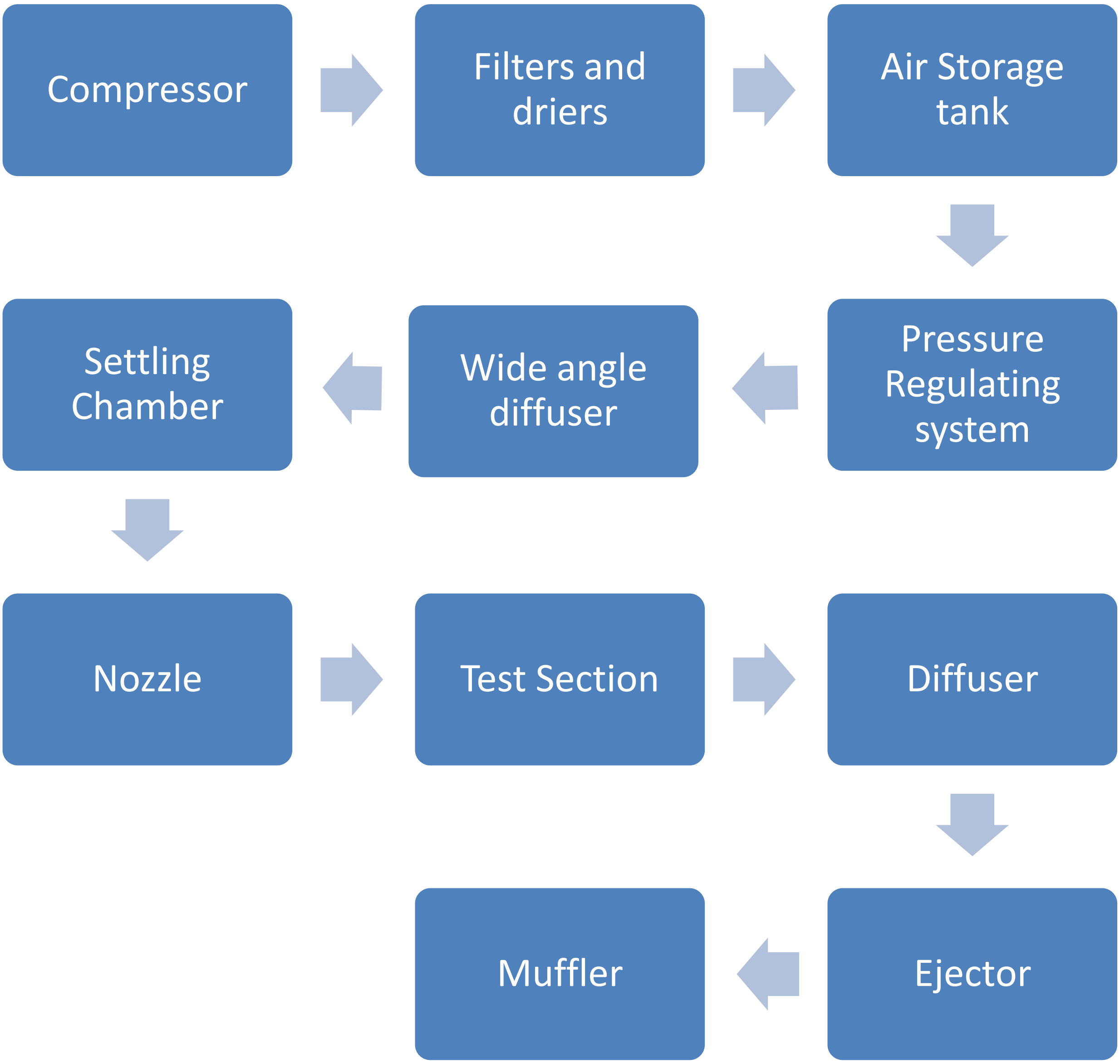


Figure 4: General Layout of a Trisonic wind tunnel

1. High Pressure System (Reservoir)

The power requirements for accelerating the flow are tremendous, so most of the high speed wind tunnels do not work continuously but stores the compressed air and releases it in the time of blow down. This is why most of the high speed wind tunnels are having large storage tanks for keeping the compressed air.

There are various types of compressors which are used for compressing the airand filling it in the storage tank of the wind tunnel, but the most frequently used compressor is the piston type. The reason behind using the piston compressor is generally being economical and its commercial availability easiness. For the effective operating of the wind tunnel the air storage pressure and the discharge pressure of the compressor should be greater than that of the tunnel operating pressure condition.

The pressure requirements for working in lower Mach number is low but the nozzle throat is large therefore the mass flow also increases. As the Mach number is raised the pressure requirement increases but the nozzle throat area decreases. The mass flow requirements are generally low for higher Mach numbers.

The high pressure compressor unit also consists of moisture absorber and cooler. The moisture absorbing unit implies the air is passed through a pressure vessel filled with an adsorbent media such as activated alumina, silica gel, molecular sieve.

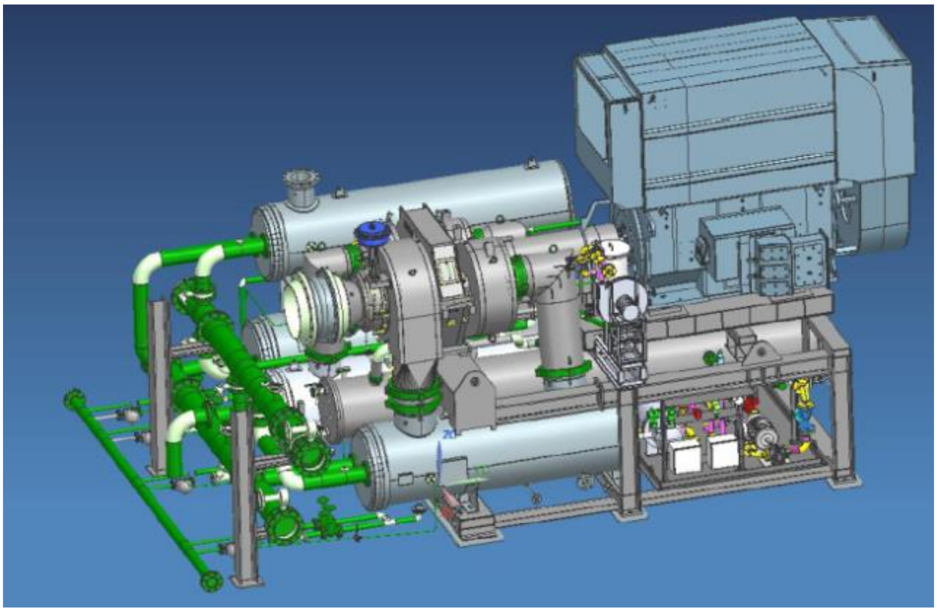


Figure 5: Compressor Unit

2. Settling chamber

The settling chamber is used for obtaining a uniform, steady flow to avoid turbulence in the section. It is capable of making the flow stream line. It is located between the PRV and the Flexible plate Nozzle.

It is circular in cross section and consists of the following major parts:

1. Wide Angle Diffuser
2. Silencer section – Consists of sound absorbing baffles
3. Settling chamber section – Consists of a honeycomb and five screens to reduce the turbulence intensity and flow angularity to respectively
4. Contraction Section – For transition of airline from circular to rectangular.

The static pressure in the settling chamber is higher than at any downstream point in the tunnel. However, it is normally considerably below that in the storage tank or in the piping to the pressure regulator. Most of the high speed wind tunnels are designed with screens in the settling chamber to promote flow uniformity and to reduce the turbulence level before the air is expanded through the nozzle.

3. Flexible nozzle

In order to achieve the desired design Mach number trisonic wind tunnel system has adopted flexible nozzle which consists of more than 1000 components and weighing 200 tons. Wall contouring by means of screw type jacks attached on the outer surface of flexible plates and nozzle contour is adjusted to that of desired Mach number by use of jacks. Jack station installed at the downstream end controls test section angle of the supersonic/subsonic test section hinging the flexible nozzle. Thus surface becomes continuous without any steps or gaps between the nozzle and the test section.

4. Transonic test section (TTS)

To test models in transonic regime TTS with slotted wall and porous wall is installed into the plenum chamber which mitigates shock reflections at transonic mach numbers. The plenum is internally lined with sound absorbent wool to absorb acoustic disturbances during the test

It also has additional blow-off provision to achieve Mach number trim in transonic testing. The TTS is attached to Flexible Nozzle on the upstream and the model cart on the downstream by means of hydraulically actuated locking pins.

5. Model Cart

Model is attached into the model cart by using a sting housing the Model Incidence Mechanism (MIM).The strut of which is moved in the vertical plane by a ball and screw mechanism actuated by a servomoter. MIM provides yaw and pitch by using Twin Roll Mechanism (TRM). Horizontal and Vertical Flaps are also provided that induces live Mach sweep from M1.2 to M1.6.

6. Diffuser System

The diffuser system comprise of various subsystem including variable diffuser, movable diffuser fixed diffuser and choke. It is mated immediately after the test section. The diffuser helps to the expansion of the air stream.

Generally, the variable diffuser will be connected with the model cart and the movable diffuser is having a parallel top and bottom walls and having side walls that shall be moved inwards which can improve the flow starting process at supersonic speed regimes.

The movable diffuser is used when we are testing under transonic wind speeds. During the testing in transonic wind speeds the transonic test section has to be integrated with the tunnel circuit. The presence of this test section will increase the overall facility length which is undesirable. Hence movable diffusers are used in such a way that I will slide into the fixed cylinder resulting in the reduction of the overall length.

7. Fixed Diffuser & Ejector

Here the airflow is decelerated due to gradual divergence of the fixed cylinder. It also contains the ejector section, consisting of 6 chevron nozzles operating at M=3. These nozzles produces high velocity jets that eventually reduces the operating pressure of the tunnel aiding in the reduction of the magnitude of the start- stop loads of tunnel.

8. Muffler system

After traversing through the diffuser and ejector systems airflow is delivered into the muffler system which consists of 2 main mechanical components namely Baffles and Ring to attach the Wide Angle Diffuser. This attenuates the aerodynamic noise produced by the airflow through the wind tunnel flow path, to acceptable levels.

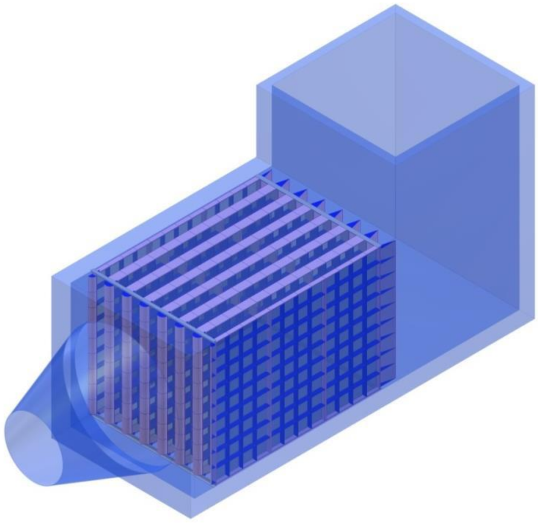
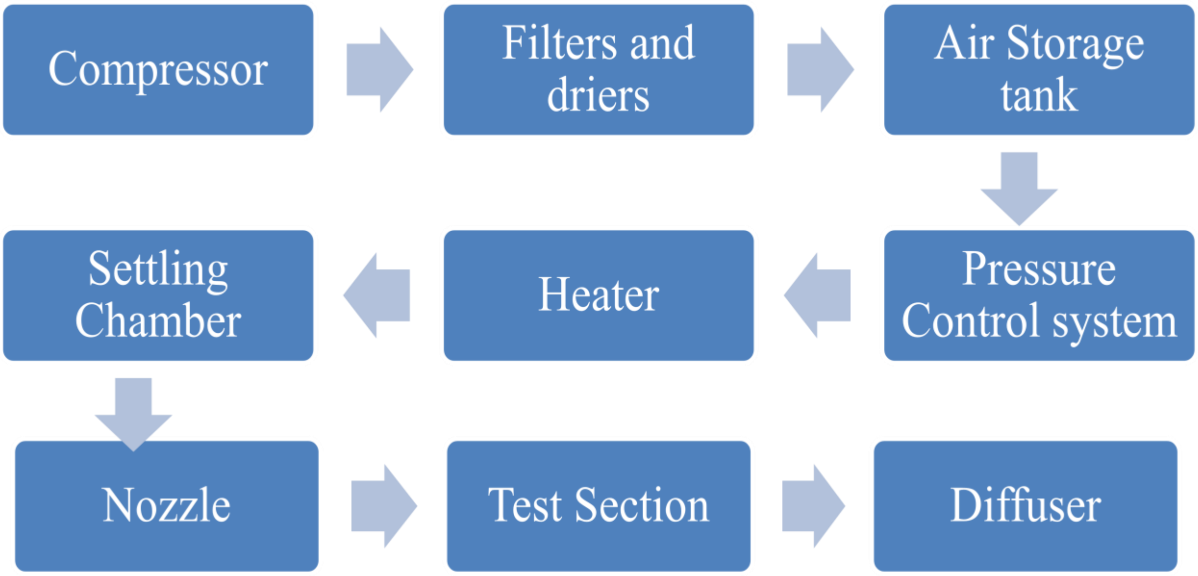


Figure 6: Muffler System

Hypersonic Wind Tunnel Facility

There are a number of experimental aerodynamic facilities that allow testing and research to be done at hypersonic velocities, one such facility is the Hypersonic Wind Tunnel Facility in VSSC, Trivandrum consisting of Hypersonic Wind Tunnel and Shock Tunnel Unit. We got a splendid opportunity of visiting the facility in VSSC. For such high speeds to be duplicated in the wind tunnels, it is essential to raise the static temperature, static pressure. At high temperatures, the characteristics of air are completely different and the enthalpy no longer increases linearly with temperature and the ideal gas law is no longer valid due to dissociation and ionization effects coming into effect.

A hypersonic wind tunnel is designed to generate a hypersonic flow field (Mach 5 to 20) in the working section. Because of the high power requirements, hypersonic wind tunnels are often of the ‘intermittent type’ .The compression ratio requirements are so high that a pressure-vacuum tunnel is dictated. It is not practical to operate with atmospheric inlet pressure (as with the in draft tunnel) or with atmospheric discharge pressure (as with the blow down tunnel).Since the temperature drops with the expanding flow, the air inside has the chance of becoming liquefied. For that reason, preheating is particularly critical.



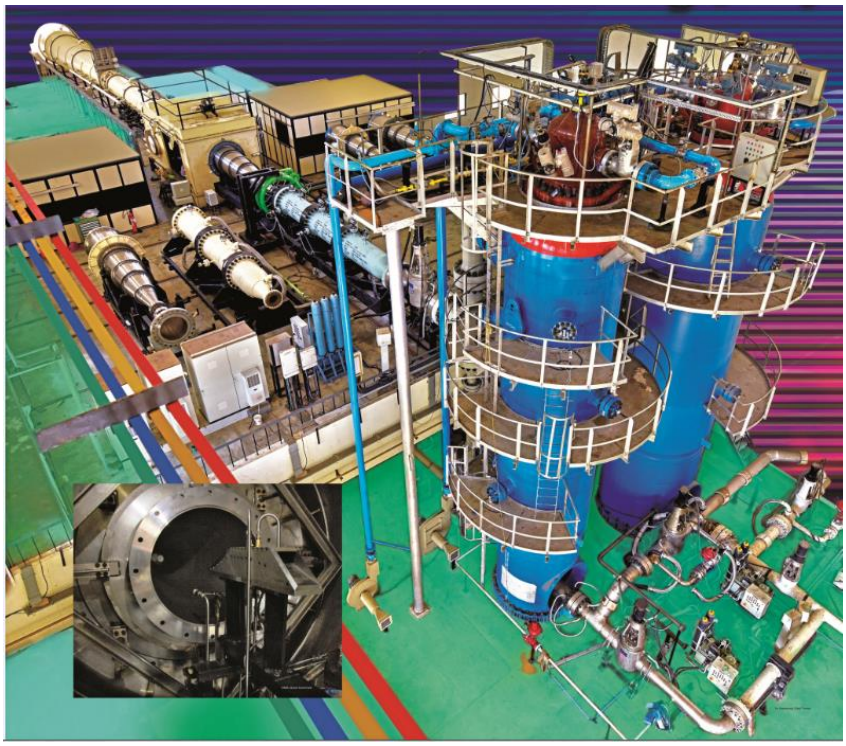


Figure 7: Hypersonic Wind Tunnel

Shock Tunnels

Shock tunnels are wind tunnels that operate at Mach numbers to 25 or higher for time intervals up to a few milliseconds by using air heated and compressed in a shock tube. The shock tunnel includes a shock tube, a nozzle attached to the end of the driven section of the shock tube, and a diaphragm between the driven tube and the nozzle. When the shock tube is fired and the generated shock reaches the end of the driven tube, the diaphragm at the nozzle entrance is ruptured. The shock is reflected from the end of the driven tube and the heated and compressed air behind the reflected shock is available for operation of the tunnel.

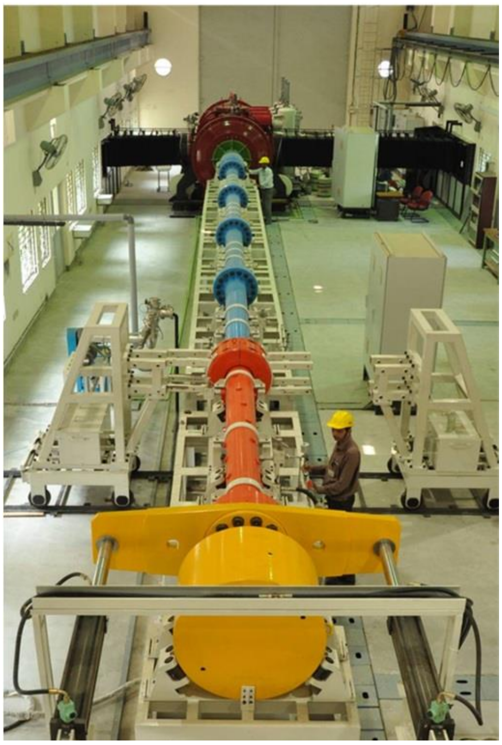


Figure 8: Shock Tunnel Facility

CHAPTER 3

STANDARD MODELS

Standard models are basically designed and generated for the calibration purpose of wind tunnels. They are having pre defined values of various parameters that are measured in wind tunnel for various dimensions of the same design. The standard model test consists of estimation of forces and moment on the model is aiming at determining its aerodynamic coefficients in various Mach number ranges.

Standard models:

- Basic finner model - Long slender body model category
- NASA 203BC model - Bluff body category
- AGARD B model - Wing body category
- 10 degree cone model - Tunnel noise measurement

AGARD B Model

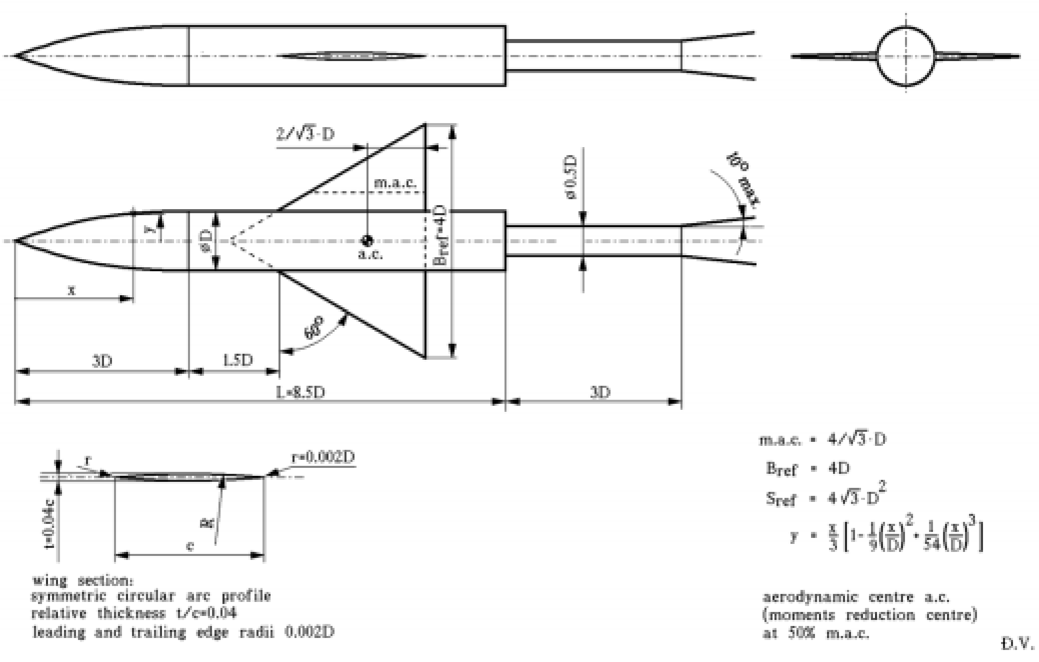


Figure 9: Geometric details of AGARD B Model

The AGARD B model is a generic winged missile configuration and is used as a standard reference for force and moment measurements. The AGARD B calibration standard model is cylinder with delta wing with a conical nose. The wing has a span of 4 times the body diameter. The wing has 4 % thickness to chord ratio.

Each and every standard model will have a predefined value on standard wind tunnels on various flow speed regimes. At first AGARD B is generally used only for supersonic wind tunnels only but now it is also often used for calibrating transonic wind tunnels also. It is a configuration consisting of wing and body combination. The forces and moments on the model at various Mach numbers are predefined which can be obtained in various experimental papers and journals. What we do is that we will compare those values to the experimental values that we obtained in the wind tunnel that is required to be tested and estimated weather the wind tunnel is working properly and the values that we obtain in other test would be correct or not.

Details of the model are given below

Type of Wing	Delta wing
Aero foil	NACA0012
Chord length of Aero foil	351.7mm
Model length(L)	1150.9mm
Model diameter(D)	135.4mm
Wing span	541.6mm
Length of Conical section	406.2mm
Angle between wing and fuselage	60˚

Table 2: Details of the Model

CHAPTER 4

METHODOLOGY OF EXPERIMENTATION

This section deals with objective of the experiment, details of the models used, test conditions and methodology of the experiment

5.1 Objective of the Test

To estimate the flow angularity and to estimate start and stop loads and flow forces over AGARD B standard model in 1.2m×1.2 m Trisonic wind tunne

5.3 Test Conditions

The model is planned to be tested under various conditions which are listed below. The variation of pressure with and without ejector on various Mach numbers is listed on the table below.

Mach Number (M)	Static Pressure without Ejector P, bar	Static Pressure with Ejector P,bar
0.2	1.7	0
0.6	5	0
0.7	2.8	1.2
0.8	1.68	0.88
1	1.63	0.87
1.2	1.68	0.9
1.4	1.81	0.91
1.8	2.29	1.14
2	2.64	1.17
2.5	3.5	1.2
3	5	1.5
3.5	7.8	1.7
4	10	2.5

Table 3: Pressure - Mach number distribution

5.4 Methodology of experimentation

Inorder to calibrate the wind tunnel it is essential to determine the start and stop loads and flow angularity of the trisonic wind tunnel. For the same we compare the established loading over standard model with respect to the trisonic wind tunnel conditions.

5.5 Analytical Solution

Equations considered;

Isentropic relations

1) $\frac{P}{Po}=(1+\frac{\gamma-1}{2}M^2)^{\frac{-\gamma}{\gamma-1}}$

2) $\frac{T}{To} = (\frac{P}{Po})^{\frac{\gamma-1}{\gamma}}$

3) Speed of sound,a= $\sqrt{\gamma\frac{P}{\rho}} = \sqrt{\gamma RT}$

4) Mach number, M = $\frac{v}{a}$

5) Starting load Normal force coefficient,

$$C_{NS} = \frac{2\gamma(M^2-1)}{(\gamma+1)(1+\frac{\gamma-1}{2}M^2)^{\frac{\gamma}{\gamma-1}}}$$

6) Maximum Normal force

$$F_{NM} = C_{NS} \times p_t \times S$$

7) Steadyload

$$F = C_F \times \frac{1}{2}\rho V^2 A$$

Where,

P = Static pressure

Po = Stagnation pressure

γ = Ratio of specific heats

T = Static temperature

To = Stagnation temperature

ρ = Density of the fluid

R = Specific gas constant (287 J/kgK)

v = Velocity of fluid in medium

P_t =Total pressure of tunnel flow at time the shock system passes over the mode

S = Lifting surface planform area

C_F= Coefficient of Force

A = Area of cross section

a =Speed of sound in air

AREA OF LIFTING SURFACE,

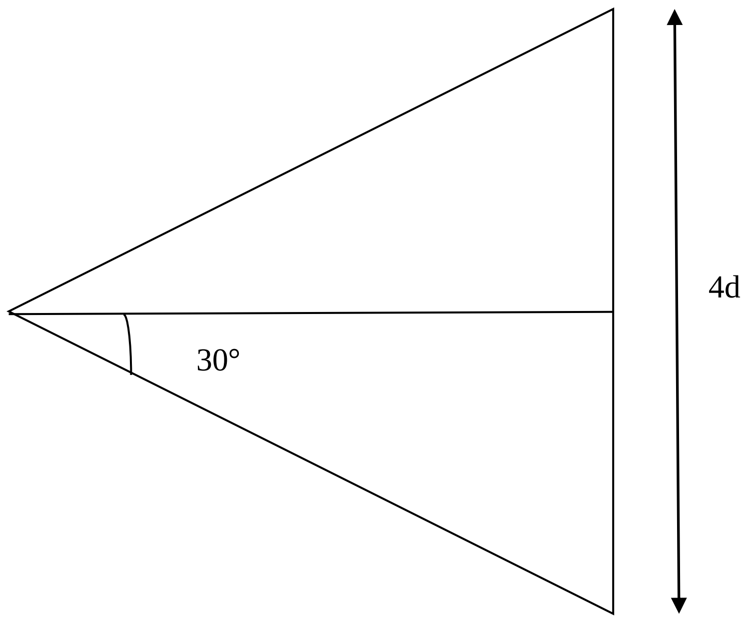


Figure 10: Top View of wing section

$\frac{A_{model}}{A_{tunnel}} = blockage(should\ be\ 1\%)$

A_{tunnel} =1.2×1.2m^2 =1.44m^2

A_{model} = 0.0144m^2

$\frac{\pi}{4}$d^2=0.0144m^2

ie ,d = 0.135 m

Height, h= $\frac{2d}{\tan 30} =$ 0.467 m

Planform area of lifting surface, S =$\frac{1}{2}$×b×h =$\frac{1}{2}$ ×4 ×0.135×0.467 =0.126m^2

Stagnation temperature, To = 300 K

CHAPTER 5

STARTING LOAD ESTIMATION

Supersonic tunnels could be started by opening a quick operating valve which induces air flow. Quick starting is desirable in all supersonic tunnels as it is subjected to high loads during the starting process which also conserves air. Whenever the tunnels are started the normal shock system passes through the test section and large forces are imposed on the model. This makes the model oscillate vigorously at the natural frequency of the model support system and normal force loads of 5 times those which the model would experience during steady flow in the same tunnel happens.

From the book High speed wind tunnel testing by Alan Pope

Starting load Normal force coefficient,

$$C_{NS} = \frac{2\gamma(M^2-1)}{(\gamma+1)(1+\frac{\gamma-1}{2}M^2)^{\frac{\gamma}{\gamma-1}}}$$

Maximum Normal force $F_{NM} = C_{NS} \times p_t \times S$

Mach Number (M)	Stagnation pressure (without ejector) P_o, bar	Stagnation pressure (with ejector) P_o ,bar	Starting load C_{NS}	Maximum normal force F_{NM} (without ejector) , N	Maximum normal force F_{NM}) (with ejector N
1.2	1.68	0.9	0.212	0.109	0.058
1.4	1.81	0.91	0.352	0.255	0.128
1.8	2.29	1.14	0.455	0.754	0.375
2	2.64	1.17	0.45	1.16	0.516
2.5	59.834	20.51	0.358	0.698	0.9261
3	183.82	55.147	0.254	5.883	1.765
3.5	600	130.77	0.172	13	2.811
4	1518.37	379.59	0.115	22.05	5.5125

Table 4 :Starting load distribution

It is noted that the maximum starting load is at Mach Number 4.

CHAPTER 6
STEADY LOAD ESTIMATION

The force experience by the model using the steady run of the tunnel is called steady load.

Steady load, $F = C_F \times \frac{1}{2}\rho V^2 A$

ρ – Airdensity

A – Area

The estimation of the force at different tunnel flow condition is given below.

From Loads on a Model during starting and stoping of an intermittent supersonic wind tunnel, K.G Winter and C.S Brown

Mach number (M)	Velocity of fluid V, (m/s)	Density of fluid (without ejector)ρ ,(kg/m^3)	Density of fluid(with ejector) ρ, (kg/m^3)	Coefficient of lift C_L	Coefficient of drag C_D
0.2	69.09	1.994×10^{-5}	0	0.0606	0.0274
0.6	201.18	6.23×10^{-5}	0	0.0564	0.0284
0.7	231.84	3.57×10^{-5}	2.123×10^{-5}	0.0586	0.0282
0.8	261.52	2.201×10^{-5}	1.757×10^{-5}	0.05	0.03
1	316.93	2.272×10^{-5}	2.295×10^{-5}	0.066	0.04
1.2	367.10	2.513×10^{-5}	3.265×10^{-5}	0.08	0.06
1.4	411.978	2.926×10^{-5}	4.682×10^{-5}	0.11	0.8
1.8	486.81	4.383×10^{-5}	12.54×10^{-5}	0.15	0.9
2	517.55	5.519×10^{-5}	19.14×10^{-5}	0.18	0.13
2.5	577.87	9.17×10^{-5}	53.58×10^{-5}	0.27	0.155
3	621.72	1.14×10^{-4}	0.0017918	0.3	0.15
3.5	654.15	3.126×10^{-4}	0.0051956	0.35	0.135
4	677.6	4.88×10^{-4}	0.0185165	0.48	0.13

Table 5: Lift and Drag coefficient distribution

Mach number M	Lift force (without ejector)	Lift force (with ejector)	Drag force (without ejector)	Drag force (with ejector)
0.2	4.15×10^{-5}	0	1.878×10^{-5}	0
0.6	0.001	0	5.6×10^{-4}	0
0.7	8.1×10^{-4}	0.0005	3.9×10^{-4}	0.000232
0.8	0.005	0.004	0.00032	0.00026
1	0.0011	0.0011	0.00066	0.00064
1.2	0.002	0.0025	0.0015	0.0019
1.4	0.0039	0.0063	0.029	0.046
1.8	0.0112	0.0321	0.067	0.19
2	0.0192	0.0664	0.014	0.05
2.5	0.059	0.3488	0.03417	0.200
3	0.1361	1.4996	0.06804	0.7497
3.5	0.337	5.6038	0.13	2.161
4	0.774	29.386	0.21	7.958

Table 6: Lift and Drag force distribution

The coefficient of lift and coefficient of drag v/s Mach number curve is plotted below

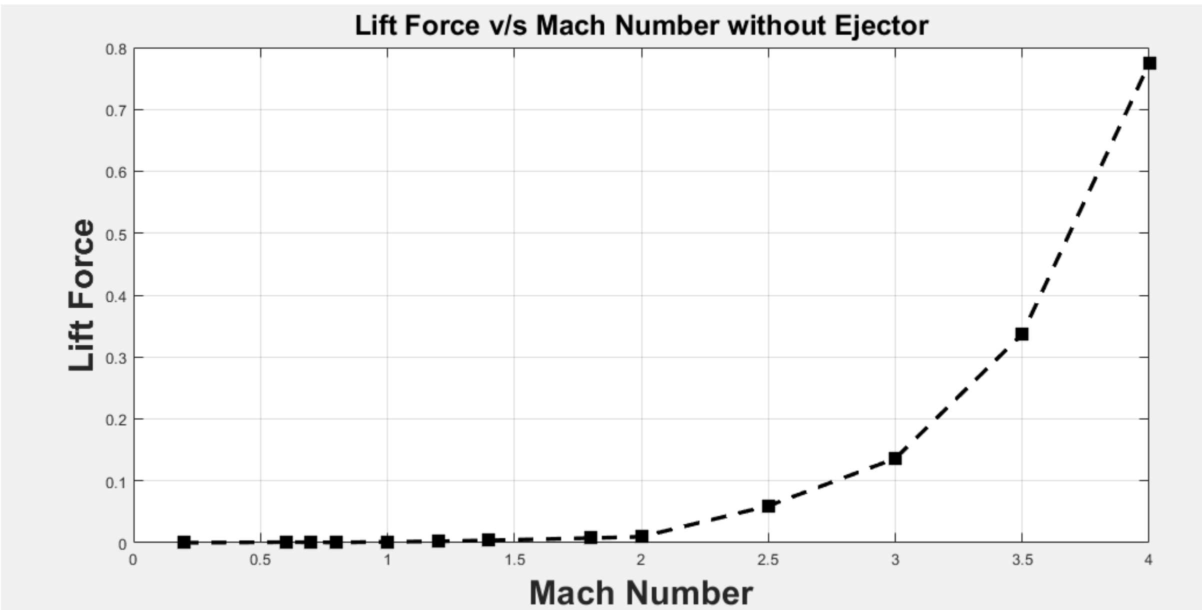


Figure 11: Lift force (N) v/s Mach number curve (without ejector)

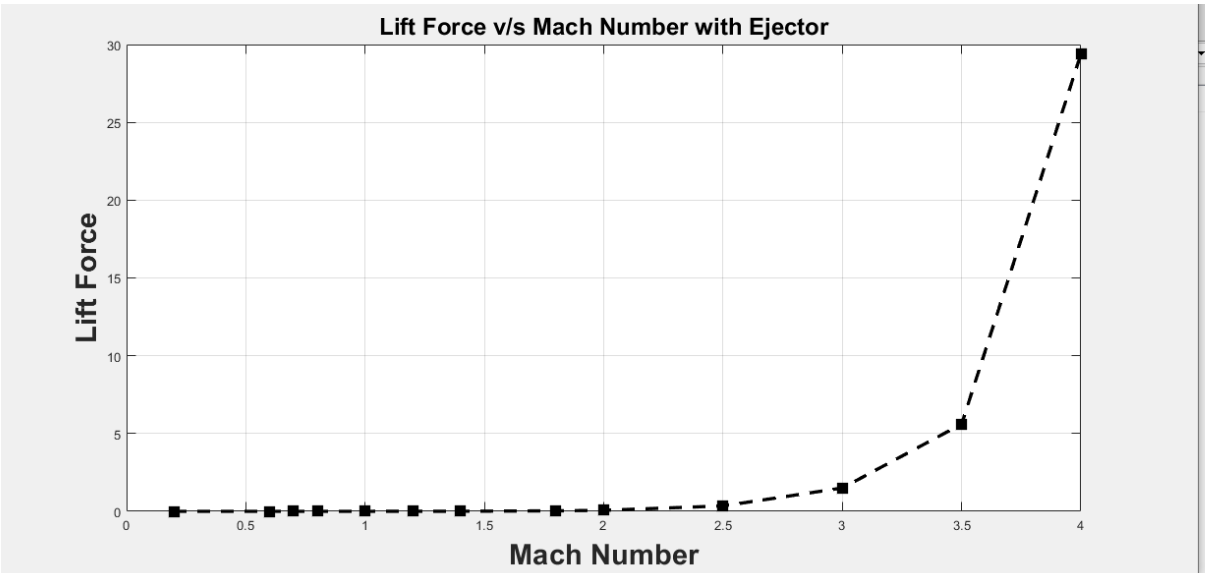


Figure 12: Lift Force (N) v/s Mach number curve (with ejector)

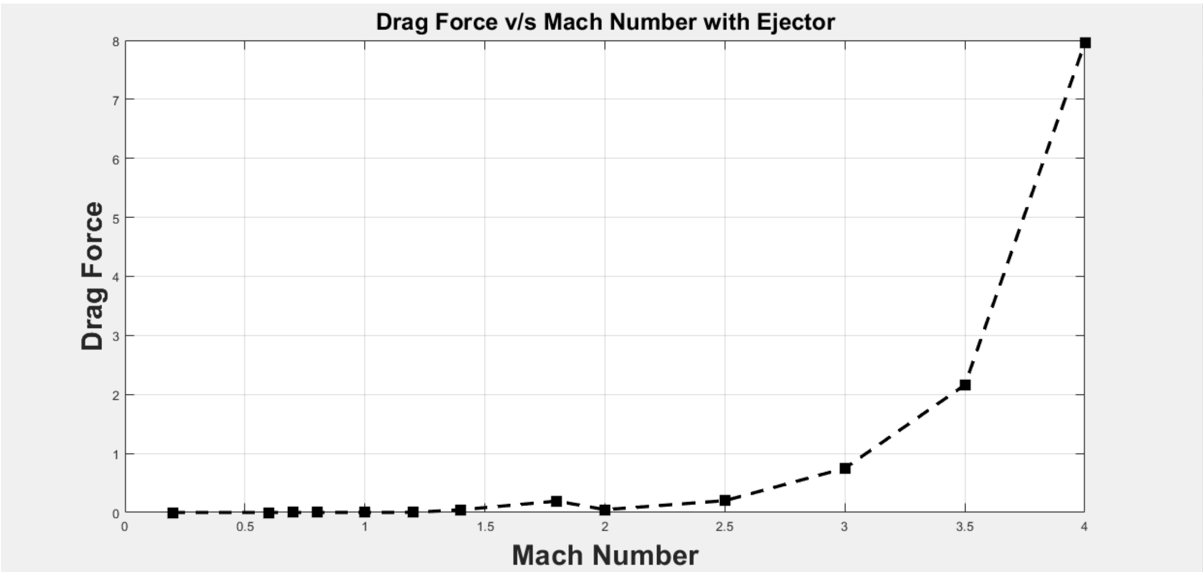


Figure 13: Drag Force (N) v/s Mach number curve (with ejector)

Hence, it can be noted that the max. steady load without and with ejector are .774 N and 29.386 N respectively at M = 4.

CHAPTER 7

FLOW ANGULARITY MEASUREMENT USING FIVE HOLE PROBE

A Five-hole wedge probe was used for the measurement of flow angularity in 1.2 m tunnel, though a five-hole probe gives flow angularity measurements at a particular point in the test section. A program is developed in Matlab to calculate the flow angularity from the pressure data acquired. The programme is validated using The program is validated using the flow angularity measurements test carried out in the Mach number range of 0.3 to 2.0 using a fivehole wedge probe in a typical Trisonic Wind Tunnel. The angle of incidence was varied in the range of -2° to 2° at the rate of$0.5°/s$. The wedge probe was tested in normal and inverted roll orientation i.e, 0° and 180°respectively and pitch angle pressure coefficient (C_α) isderived. The angle of incidence where the C_α is zero was determined for normal and inverted probe roll orientation and identified as α_N and α_I respectively.

Flow angularity in pitch plane (α_F) $= -\dfrac{(\alpha_N+\alpha_I)}{2}$

Probe error in pitch plane (α_P) $= \dfrac{(\alpha_N-\alpha_I)}{2}$

Where,α_N = Normal probe roll orientation

α_I = Inverted probe roll orientation

Pitch angle Pressure coefficient,

$$C_\alpha = (P_3 - P_1) / (P_5 - P_{avg})$$

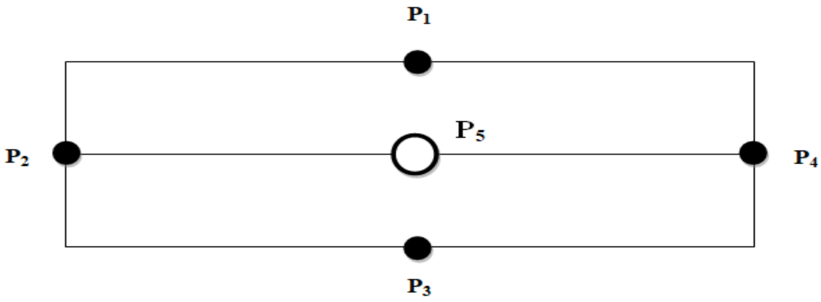


Figure 14: Typical Five Hole Probe (front view)

Sl no	Mach No.	α_I	α_N	$\alpha_F = -(\alpha_N + \alpha_I)/2$
1	0.2	-2.25	-2.17	2.21
2	0.4	-1.802	-1.89	1.84
3	0.6	-1.49	-1.45	1.47
4	.84	-1.2	-1.1	1.15

Table 7: Flow Inclination values obtained using a five hole wedge probe

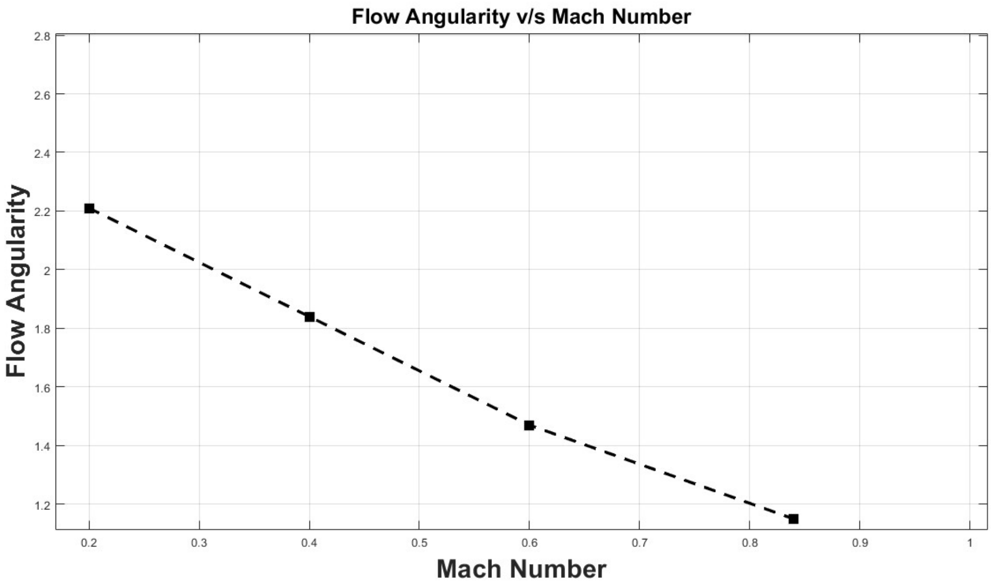


Figure 15: Mach number v/s Flow inclination curve (Degrees)

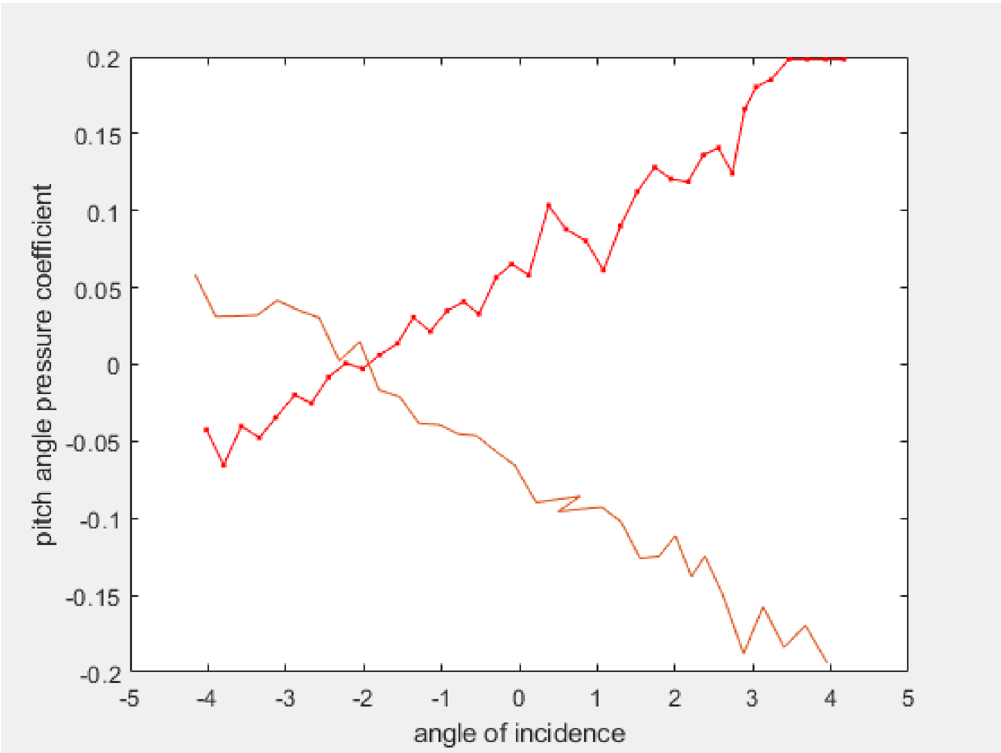


Figure 16: Angle of Incidence v/s Pitch angle pressure coefficient curve for .2 M

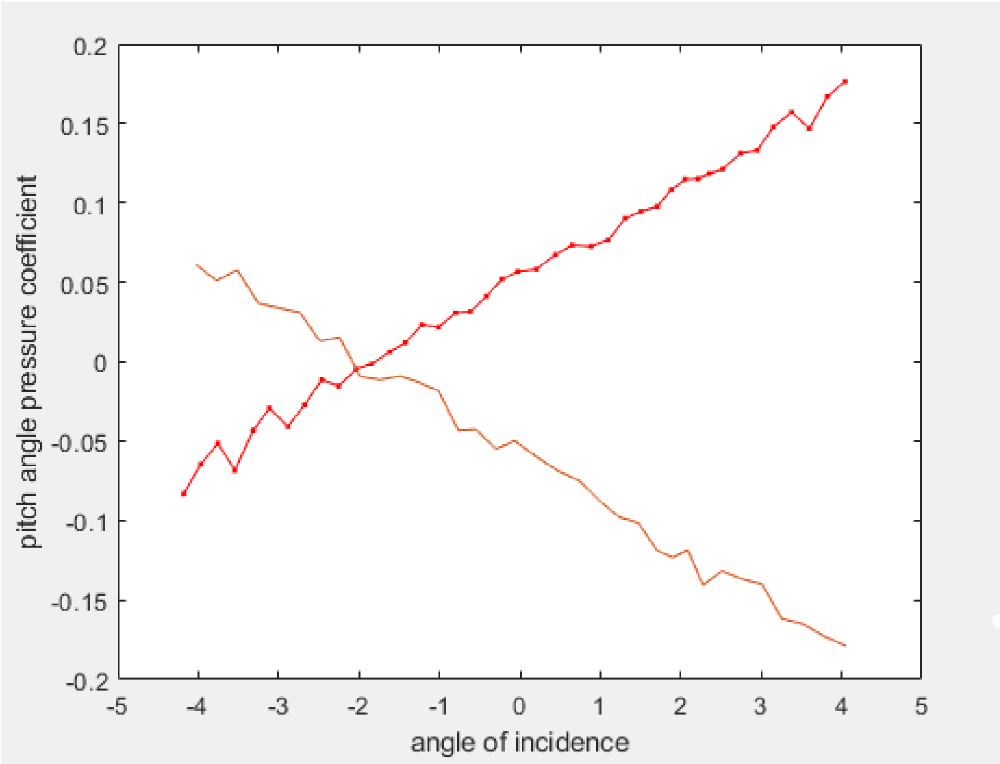


Figure 17: Angle of Incidence v/s Pitch angle pressure coefficient curve for .4 M

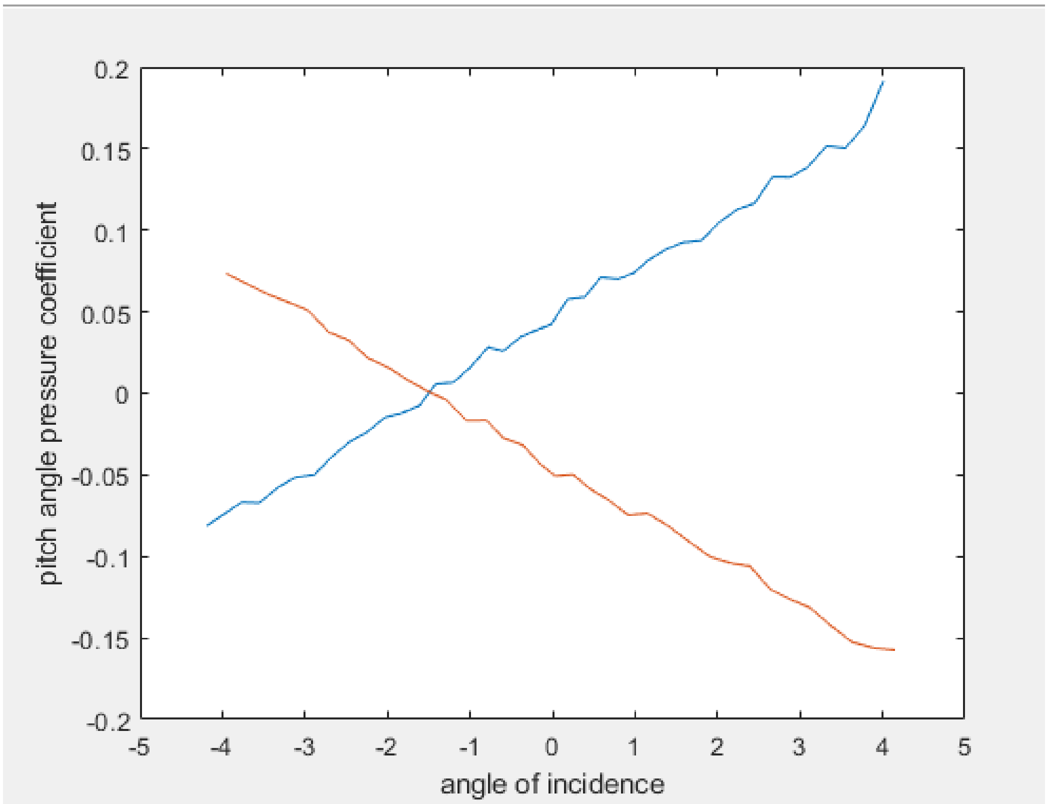


Figure 18: Angle of Incidence v/s Pitch angle pressure coefficient curve for .6 M

APPENDIX:1

MATLAB PROGRAMMING:

```
p1 = [Pressure values at port 1];

p2 = [Pressure values at port 2];

p3 = [Pressure values at port 3];

p4 = [Pressure values at port 4];

p5 = [Pressure values at port 5];

pavg = (p1+p2+p3+p4)/4

ca = (p3-p1)./(p5-pavg)

a= [angle of incidence for which p is calculated]

p1i = [Pressure values at port 1 in inverted condition];

p2i = [Pressure values at port 2 in inverted condition];

p3i = [Pressure values at port 3 in inverted condition];

p4i = [Pressure values at port 4 in inverted condition];

p5i = [Pressure values at port 5 in inverted condition];

pavgi = (p1i+p2i+p3i+p4i)/4

cai = (p3i-p1i)./(p5i-pavgi)

ai= [angle of incidence for which pi is calculated]

plot(a,ca,ai,cai);

x= interp1(ca,a,0);

x= interp1(cai,ai,0);
```

CONCLUSION

I. As part of training 1m Hypersonic Wind Tunnel, 1m Shock Tunnel and 1.2m Trisonic Wind Tunnel (being developed) are visited. Learned about its subsystems and their functionality.

II. Learned about the calibration of wind tunnel and various standard model used for wind tunnel calibration.

III. AGARD B model is selected to calibrate 1.2m Trisonic Wind Tunnel. The start-stop and steady load on the model at various Mach no. is estimated. The max. load 22.05 N at M= 4.

IV. A MATLAB program is developed to calculate flow angularity from five point probe pressure data. A typical Trisonic wind tunnel data is taken to validate the program.

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